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Invention: SENSOR DEVICE AND METHOD OF DETECTING
GASES OR FUMES IN AIR

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ENGLISH LANGUAGE TRANSLATION OF THE
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Technical field:

The Invention relates to a sensor device and the method for detection of gases or vapors contained in air by way of an electrically heatable sensor element, for example for the detection of gases and vapors in the guidance of breathing air of a gas mask.

State-of-the-art

The following printed documents are known: DE 3613512; EP 0447619; EP 0535385; GB 2266467; DE 4132680; EP 0410071; EP 0343521; WO 9612523 for the construction of gas sensor systems and in particular for the sensor technical surveillance of a breathing protective masks.. The teaching provided by the state-of-the-art employs different sensor technologies:

1. Electrochemical cells: it is disadvantageous in the employment of electrochemical gas detection cells that these cells more or less selectively react to some gases. Therefore the application of these cells is subject to the precondition that essentially only a single gas has to be detected, which gas

in addition has to be a known gas. In a practical situation it is evaluated as disadvantageous that this method is questionable based on this limitation in connection with several potentially dangerous gases (for example in the chemical industries). In addition to, the lifetime of electrochemical cells is limited. The cells are also very expensive.

2. Color change reactions, such as they are known from test tubes available commercially. The strong selectivity is a disadvantage of this sensor technology. This requires the precondition that the gases to be monitored are known. It is a further disadvantage that the chemical reactions employed for the color change detection are frequently not reversible, thus one-way sensors are present which have to be selected especially prior to each deployment and to which cannot be employed again in the following.

3. Metal oxide sensors according to the Taguchi principle: the advantage of the sensors includes that they react to all gaseous or vaporous substances in the air, which are oxidizable or reduceable. Depending on the composition of the gas sensitive layer, the electrical resistance is for example decreased

by oxidizable substances. Reduceable substances increase the electrical resistance in this case. The disadvantage is that the sensors have to be heated, which uses up energy and which furnishes narrow limits to an operation of the sensor system with batteries. The substantial drift of the sensor value in standard air, for example when the air temperature changes and/or when the air humidity changes are a substantial disadvantage.

Each Taguchi sensor exhibits an electrical semiconductor as a gas sensitive layer. All semiconductors change for example their resistance amongst others with the temperature. In addition, the reaction speed and the sensitivity of the sensor element changes relative to the intended gases such that the characterizing curves relative to the different gases can be substantially different from each other at different temperatures. For these reasons it is necessary to maintain the temperature of the gas sensitive semiconductor layer stable within narrow limits.

Even in case where the temperature of the heating structure could be maintained completely constant, this would nevertheless not reach a constant

temperature of the gas sensitive layer under all circumstances, since the temperature gradient between the gas sensitive layer and the surrounding air is very large and since the temperature gradient is influenced by the emitted by the sensor element through radiation and convectively. The heat amount delivered by the sensor element to the ambient is on the one hand a function of the temperature gradient, on the other hand a function of the flow speed of the air relative to the sensor element.

Practically, one will always determine substantial variations of the sensor resistance despite expensive electronic automatic controls, which has limited in the past the deployment of semiconductor sensors substantially, because the base resistance of the gas sensitive layer massively varies with temperature.

It is known to evaluate sensor signals such that the actual signals of the sensor are compared with an average value of preceding sensor signals formed over a certain time period. This means the difference between the actual signal and the average value is evaluated. For example a switching

signal can be released in case the amount of this difference surpasses a defined value.

If sudden events occur, to which the sensor responds, then these sudden events can be very well detected with this method. Slow and/or only small changes of the sensor resistance in contrast do not lead to any evaluations or, respectively, switching signals.

Slow changes of the actual sensor signal are ignored, where the slow changes can be caused either by a drifting behavior of the sensor itself or however by a change of the concentration of a vapor or gas addition in the ambient air.

In contrast reliably a switching signal is generated upon occurrences of sudden concentration increases of oxidizable gases in the ambient air.

In many cases it is however very important that also a slow rise of gas concentrations can be reliably detected. This is for example important in the

monitoring of breathing protective masks, because for example the filter of the breathing protective mask typically does not suddenly lose its functioning upon a set duration of the filter, but the deposit power of the filter in most cases becomes creepingly worse. In addition the concentration of toxic gases can increase very slowly, which increase would have to be detected at any rate. The above illustrated method of the signal evaluation cannot be employed for this purpose without modification for the reasons recited.

The present state-of-the-art does not furnish a useful teaching as to how the Taguchi sensors can be employed in applications despite the apparent stability disadvantages of the Taguchi sensors, wherein the applications require safety with respect to erroneous alarms and the simultaneous capability of the detection of also small concentrations and/or small concentration changes.

Technical purpose:

Therefore it is an object of the Invention to furnish a method and the sensor device for detection of gases or vapors contained in air, in particular in breathing air, with a high safety against erroneous alarm, wherein also small concentrations and/or small concentrations changes can be detected.

Disclosure of the Invention and its advantages:

This object is accomplished according to the present Invention by a sensor device for detection of gases or vapors contained in air with a sensor element, wherein the sensor element exhibits a gas sensitive layer and wherein the sensor element is electrically heatable with a heating structure, and wherein the sensor element is disposed in a casing, wherein the casing the shields the sensor element from air motions occurring outside of the casing, characterized in that the casing exhibits the diffusion layer, wherein a passage of gas and vapor from the outside into the interior of the casing and vice versa is possible through the diffusion layer by diffusion and wherein the casing and the diffusion layer are constructed heat insulating or thermally insulating.

The object of the invention is resolved according to the present invention by a method for operating sensor element for detecting gases or vapors contained in air, which sensor element exhibits a gas sensitive layer and is heatable electrically with a heating structure, characterized in that the temperature of the sensor element is controlled and the temperature set value is at least for a certain time changed depending on the size or the time behavior of the sensor signal with an imbalance value switched on.

A method for operating a sensor device for detection of gases or vapors contained in air with a sensor element, wherein the sensor element exhibits a gas sensitive layer and wherein the sensor element is electrically heatable with a heating structure, for performing the method is characterized in that sensor element is disposed in a casing, wherein the casing shields the sensor element from air motions occurring outside of the casing, wherein the casing exhibits a diffusion layer through which a passage of gas and vapor from the outside into the interior of the casing and vice versa is possible based on diffusion.

Applications are amongst others in the protection of human beings, where the human beings employ the breathing protection equipment (for example breathing protection masks). A further application comprises the monitoring of air conditioning and ventilation plants with respect to an (undesired) presence of gases and vapors. Furthermore, the ventilation of motor vehicles can be controlled with the gas detectors according to the present invention such that the ventilation is interrupted in case gas concentrations are detected outside of the vehicle. Furthermore, the ventilation of the rooms or buildings as required can be performed with the gas detectors according to the present invention such that the ventilation rate is coupled to the concentration of for example organic air contents materials (gases, vapors). Furthermore, the monitoring of the air with respect to ignitable or, respectively explosion endangering gas air mixtures can be performed with the gas detectors according to the present invention.

The sensor of the sensor device indicated according to the present invention

is a Taguchi sensor which exhibits and electrical semiconductor as a gas sensitive layer such as does every Taguchi sensor.

It is necessary for this purpose to maintain the temperature of the gas sensitive semiconductor layer stable within narrow limits. Already temperature automatic controls of sensors are known for this purpose, wherein some temperature automatic controls exploit the fact that the sensors exhibit heating structures made of platinum or another material with a pronounced temperature coefficient. Methods are known to a person of ordinary skill in the art how such heaters can be controlled such that the resistance of the heater is employed as an ACTUAL reference.

The sensor element exhibits a sensor substrate, a gas sensitive layer and a heater structure disposed between the sensor substrate and the gas sensitive layer. The heating structure is controlled electrically through an external resistor, wherein the external resistor is dimensioned such that the current flow in no case heats the sensor element to the set point temperature. Instead periodically an impulse is delivered to a switching device component

through a control line from a central control and automatic control apparatus, advantageously formed as a microcontroller, wherein the switching device component delivers an energy rich switching pulse to the heating structure. The outer resistance and the heating structure form a voltage divider.

After switching off this power then that voltage is measured through a first analog/digital converter, which voltage is taken off at the voltage divider between the heating structure and the outer resistance.

If the voltage is too high, then the heating pulse for the number of heating pulses is shortened during the next periods. If in contrast the voltage should be too small, then the heating pulse or the number of heating pulses is lengthened during the next periods.

The impedance of the gas sensitive layer of the sensor element is measured with the central control and automatic control apparatus, suitable software and a second analog/digital converter, wherein the second analog/digital

converter is connected to the gas sensitive layer and the impedance is thereby available as a signal for evaluation. Only the ohmic resistance is measured here in the most simple case.

Even if the temperature of the heating structure would be completely constant, nevertheless no temperature constant under any circumstances of the gas sensitive layer could be achieved because the temperature gradient between the gas sensitive layer and the surrounding air is very large and is influenced by the heat emitted by the sensor element by radiation and convectively. The thermal energy delivered by the sensor element to the ambient is on the one hand a function of the temperature gradient, on the other hand a function of the flow speed of the air relative to the sensor element.

Therefore one will find in practical situations always substantial variations of the sensor resistance in standard air despite expensive electronic automatic controls, which fact has restricted substantially the employment of semiconductor sensors in the past since the base resistance of the gas entity

for layer massively varies with the temperature.

A sensor device according to the present invention therefore exhibits a sensor element which is disposed in a casing, which is air technically closed and which does not allow air motions outside of the casing any access to the heated sensor element. The casing is advantageously constructed such that its internal space is thermally insulated relative to the surroundings.

After some time a thermal balance between the heating structure, the sensor substrate as the heat storage, and the gas sensitive layer is formed in the casing, since also the air is heated to a higher level in the surroundings of the heat structure, the sensor substrate, and the gas sensitive layer and thereby the temperature gradient between air and sensor element is decreased. The undesired variations of the sensor resistance caused by the temperature gradient between air and sensor element are essentially reduced in this manner according to the present invention.

According to the present invention the casing exhibits a semi permeable

diffusion layer, which diffusion layer is practically impermeable for air flows, which diffusion layer however can be penetrated by diffusing air and gas particles. According to the present invention thus based on the different partial pressures inside and outside of the casing, gases diffuse into the casing or out of the casing through the diffusion layer, wherein however an air circulation through the diffusion layer is practically suppressed. Induced heat streams based on air motions through the semi permeable diffusion layer are therefore excluded or at least very strongly limited.

The casing including the diffusion layer is formed heat insulating and/or thermally insulating according to a preferred embodiment of a sensor device according to the present invention.

This in combination with very precise heating automatic control accomplishes that no effects of the ambient temperature show up any longer on the sensor resistor in standard air over a very wide temperature region.

It is a further advantage that the energy requirements of the sensor element

can be substantially decreased by the heat insulating and/or thermally insulating formation of the casing and of the diffusion layer according to the present invention, which is very important and advantageous in connection with operating with batteries.

As already recited above in connection with the illustration of the state-of-the-art, it is known to evaluate the difference between the actual signal and an average value. If events occur suddenly, to which events the sensor responds, then these events can be very good detected according to this method. Slow and/or only small changes of the sensor resistance lead in contrast to known evaluations or, respectively, switching signals. The actual sensor signal is average over a predetermined time period and is headed with a constant value such that an average signal results disposed on average slightly above the sensor signal which is employed as a reference signal 52. If events occur which change the value of the actual sensor signal to values above the reference signal, then a switching signal is released. Slow changes of the actual sensor signal are ignored. In contrast to that a switching signal is reliably generated upon occurrence of sudden

concentration increases of oxidizable gases in the ambient air.

However it is very important in many cases that also a slow rise of the gas concentration is reliably detected, for example in case the concentration of toxic gases increases very slowly, which must be detected at any rate. The illustrated method cannot be employed in this case without modification.

The heating power is influenced by an additional value (to the temperature) according to an invention method for operating a sensor device. An interference value switch on is performed thereby as considered by automatic control technology.

The observation that changes of the electrical parameters of the gas sensitive layer of the sensor element (resistor, capacitance, inductivity) as well as derived of the offering of oxidizable gases or reduceable gases as well as a result of very issuance of the air humidity or of the temperature are the basis of the idea of the present invention.

For purposes of simplicity only the detection of oxidizable gases is described in the following. Reduceable gases behave principally inversely, that is reduceable gases increase also for example the sensor resistance, whereas oxidizable gases reduce the sensor resistance. The invention is applicable sensibly even though also inversely, also for reduceable gases.

A method according to the present invention is illustrated in the following. At the start, the sensor in standard air delivers an actual sensor signal at a determined heating power. In the following the sensor is impacted by a gas pulse of a predetermined time duration.

In case of a not influenced heating power the actual sensor signal returns only after a longer time period to the starting value after the end of the gas pulse. A heating power with interference value switch on in contrast leads to an actual sensor signal influenced by the heating power, which actual sensor signal returns quicker to the starting value. If the heating power is always then led after for example proportional in the sense of a temperature increase in case the actual sensor signal passes through a change, then the

actual sensor signal returns significantly faster to the starting value.

It is essential that the reactions of the gas sensitive layer with the gas occur at any rate in the case of an actually present gas concentration at the sensor. The temperature sensitivity of the sensor signal is reduced by the effects and interactions of the gases. The change of the sensor signal effected by the temperature follow-up therefore is smaller during the gas impulse as compared to prior or after the gas impulse. In other words: the sensor signal reacts during the gas impulse only relatively weak to a change in the heating power and thus to the interference value switch on. The gas induced reduction of the actual sensor signal therefore assumes approximately the same course as is present in case of an otherwise identical arrangement without temperature follow-up upon leading after and following on to the heating power.

If however the reaction of the actual sensor signal is for example caused by a change of the air humidity or by a change of the air temperature, then the temperature sensitivity of the sensor signal does not change or changes only

very little. A change of the air humidity or a change of the air temperature therefore have substantial and continuing influence on the actual sensor signal in case of a not influenced heat power.

The influence of the sensor signal effected by the temperature tracking is clearly larger than in the case of a gas pulse where however already at the start of such an interaction the heating power was tracked. The monitoring of the lower explosion boundary for protection against accidents after gas linkages is also sensible. In other words: the sensor signal reacts heavily to a change of the heating power and thus to the interference value switch on. The change of the sensor value caused by a change in the air humidity or on a change of the air temperature is therefore not only much smaller, but also timewise clearly shorter than in the case of a not influenced heating power.

Therefore the heating automatic control of the sensor is constructed such according to the present invention that the guiding value of the heating automatic control is the temperature and that an interference value is switched onto the automatic control values, wherein the interfering value is

derived from the deviation of the actual sensor signal relative to a standard value in case of standard air.

Both the signal processing as well as the heating automatic control can advantageously be controlled by a single single-circuit controller (uC).

A combination of

a. an arrangement of the sensor element in a preferably thermally insulated or, respectively, heat insulating casing with the thermally insulating or, respectively, heat insulating diffusion layer through which a gas access to the sensor element can be performed by diffusion without air motion,

b. a diffusion caused gas access to the sensor without air motion,

c. a heating of the sensor element by automatic control of the temperature, wherein the relative deviation of the actual sensor resistance from the resistance of the sensor element under standard conditions is switched on to

the automatic control circuit as an interference value,

comprises the advantageous result that the sensor signal follows quickly and nearly exclusively to the factual contents of oxidizable air contents substances and further exhibits by far less drifting features as hitherto known.

If an evaluation is performed which compares the actual sensor value with an average value determined over the time, then substantially less variations of the sensor signal under standard conditions can be assumed, in particular then, when the system has become stable after some time.

Therefore the time period over which the average value of the actual sensor signal is formed for solving as a comparison value relative to the actual sensor value is not constant but increases always in the course of the operating time of the system according to an embodiment of the invention.

The first comparison value is obtained from the average value over a

relatively short time period, since the system is subject to necessarily high self dynamic variations immediately after the switch on. This time period is increased after the switch on phase and this time period finally reaches a substantially longer integration time in the built-up state. A certain amount is deducted from the calculated average value in order to form the so-called reference value, since the average value in principle can coincide with the actual sensor signal.

According to a preferred variation of an embodiment the amount to be deducted is very large during the initial phase such that the reference value gets a large distance relative to the sensor value. This is important in order to prevent that signals are released in the non-built-up state, even though no significant gas concentration change occurs. The amount is successively decreased in the further course of time such that the reference value approaches more and more the sensor value in the built-up state.

Further refinements can be introduced. According to a further variation of an embodiment of the invention method the reference value is brought again

to a larger distance relative to the sensor value after violent gas induce sensor reactions, since violent reactions of the sensor lead to temporary instable sensor situations.

According to a further embodiment variation of the invention method the calculation of the average value is again performed over shorter time periods, when a gas induced strong sensor signal change has occurred. According to a further variation of an embodiment the calculation of the average value is dispensed with for that time period during which time period a gas induced sensor signal change occurs.

Despite the recited steps the actual gas level can rise in such a slow extent that the average value follows essentially to this rise. In this case slowly substantial gas concentrations can be formed without that the precedingly described release condition would be fulfilled according to which the actual sensor signal assumes a smaller value as compared with the reference value determined by calculation.

According to a further variation of embodiment therefore additionally a minimum value is fixed for the reference value, wherein the actual reference value never can become smaller than its fixed minimum value. The minimum value is selected such that this limit is not reached by sensor caused variations, and on the other hand the gas concentrations, which can be coordinated to this sensor signal, do not yet inflict permanent damages to the human being, or, respectively, in the case of for example of a monitoring of explosive limits (for example methane air mixtures) and are disposed at a far safety distance relative to the explosion limit.

If jump like changes of the humidity or temperature occur (for example upon application of the sensor at a suitable position in or at breathing protective masks for the purpose of the filtering or sealing monitoring) then the effect of these influences on the sensor resistance upon application of a method according to the present invention will be absolutely smaller and only occur temporarily.

Nevertheless an erroneous signal triggering can occur, which then would be

an undesired erroneous alarm. According to a further variation of embodiment therefore a time staggered evaluation is performed, which time staggered evaluation is illustrated in the following.

A reference value is disposed below the sensor standard level. If a gas impulse decreases the actual sensor signal by a certain amount, then the reference value is undershot and thereby the switching criterion is fulfilled. Thereby a kind of `quiet pre-alarm` is released, however according to the present invention the switching signal is not yet triggered. A switching signal is released only then when the switching criterion remains fulfilled for a certain time period, which switching signal is maintained present during the remaining time period, during which time the actual sensor signal remains below the reference value.

If in contrast a very short term and therefore practically to be neglected gas pulse occurs or if a humidity pulse to be compensated according to a method of the present invention occurs, wherein the humidity pulse triggers about a reaction of the actual sensor signal, then according to the present invention

no switching signal is triggered.

According to a further variation of embodiment of the invention method, the time period of the pre-alarm is not fixedly defined, but instead of function of the quickness of the sensor signal change or as a function of the absolute change amount over the time period. If thus a very large sensor signal change has occurred during a fixed time period, then the time period of the prealarm can be shortened. This is advantageous in order to be able to maintain the time up to the triggering of the alarm as short as possible in case of actually suddenly occurring large gas concentrations.

A similar result can be obtained if the sensor signal is average over two different time periods, for example both over time period of 20 seconds as well as over time period of 300 seconds. As previously recited a certain amount of for example 2 percent of the standard value or the like is deducted from the average value formed over the longer time period. The values determined in this way are compared with each other.

If the average value formed over the shorter time becomes smaller as compared to the average value formed by averaging over the longer time period and the value resulting after deduction of a certain amount (for example 2 percent) then a switching signal is triggered.

Frequently however it is not sensible to deduct only a constant amount from the average value for forming a reference value, since the sensor characteristic curve (sensor signal depending on the gas concentration) is usually a nonlinear curve.

In the case that the ohmic resistance of the gas sensitive layer is employed for forming the actual sensor signal, then this means that for example 10 ppm (parts per million) of a certain gas effect different resistance changes depending on the base resistance of the gas sensitive layer. Thus the relative resistance change caused by 10 ppm offered gas is substantially smaller for example in case of a low base resistance as compared with the situation at a high base resistance. This fact can be taken into consideration by taking into consideration the sensor characteristic curves of different object gases in the

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calculation of the reference value based on the determined average value according to the present invention.

The employment of the described sensor system is in particular critical when the system is taken into operation while already a substantial load of gas is present. Since the system is in fact incapable of measuring absolute concentrations but can only capture changes (relative to a reference value) within the time period of observation, then the system would not deliver any suggestion (switching signal, alarm) relative to the in fact present loading with gas.

This problem situation is resolved according to the present invention by increasing for a short time period the temperature of the gas sensitive layer according to a further variation of deployment of the invention method. The temperature increase effects on the one hand a shifting of the reaction balance within the gas sensitive layer, wherein the shifting becomes apparent via a change of the sensor signal, and on the other hand the sensor is operated for short time at a different (temperature dependent) characteristic

curve. The capturing and the evaluation of the sensor signal prior to, during, and after the short term temperature increase allows conclusions relative to a possibly present gas load.

Short description of the drawing, where there is shown:

Figure 1 a schematic representation of a sensor element with a typical known circuit, which is

employed in a preferred embodiment of the invention,

Figure 2 a schematic representation of a time sequence of a plurality of heating impulses and of

time intervals without current for temperature automatic control,

Figure 3 a detailed presentation of the sensor element (left) as well as the typical course of the

temperature in the direction perpendicular to the plane of the sensor

element (right),

Figure 4 an arrangement according to the present invention of a sensor element in a casing,

Figure 5 an example showing the time course of the sensor signal and of the heating power

according to a method for operating the sensor element corresponding to the state-of-

the-art,

Figure 6 an example for the time course of sensor signal and heating power according to a

variation of an embodiment of the invention method for operating the sensor element,

Figure 7 an example for the time course of sensor signal and heating power according to another

variation of an embodiment of a method according to the present

invention for operating

of a sensor element.

Figure 1 shows schematically a sensor element 11 with a typical known

circuit, which circuit is employed according to a preferred embodiment of

the invention. The sensor element 11 exhibits a sensor substrate 31, a gas

sensitive layer 33 and the heating structure 32 disposed between the sensor

substrate 31 and the gas sensitive layer 33 (figure 3).

The heating structure 32 is controlled electrically through an outer resistance

12 (figure 1), wherein the outer resistance is dimensioned such that the

current flow under no circumstances will heat the sensor element 11 set

point temperature. Instead of, a pulse is delivered periodically to a switching

component device 15 from a central control and automatic control device 13,

advantageously formed as a microcontroller (uC), wherein the switching

component device 15 delivers an energy rich switching pulse to the heating

structure 32. The outer resistance 12 and heating structure 32 form a voltage divider.

After turning off this pulse, the voltage is measured over a first analog/digital converter 16, which voltage is tapped at the voltage divider between the heating structure 32 and the outer resistor 12.

If the voltage is too high (heating structure 32 has an ohmic value to high, therefore the sensor temperature is too high) then during the next period the heating pulse or the number of heating pulses is shortened. If in contrast the voltage would be too small (heating structure 32 is too low ohmic, therefore the sensor temperature is too low), then the heating pulse or the number of heating pulses is lengthened during the next periods.

The impedance of the gas sensitive layer 33 of the sensor element 11 is measured with the central control and automatic control device 13, suitable software and a second analog/digital converter 18, wherein the second analog/digital converter 18 is connected to the gas sensitive layer 33, and the

impedance thereby stands available as a signal for evaluation purposes. In the most simple case only the ohmic resistance is hereby measured.

Figure 2 shows the time sequence of a plurality of heating impulses 21 and of time intervals 22 without current for illustrating the systematic of the temperature automatic control. If the temperature corresponds to the set point value, then a certain relationship exists between the number of heating impulses 21 and the time intervals 22 (figure 2 top) without current. If the sensor element 11 for example is cold, then the number of heating impulses 21 is increased and the time intervals 22 without current are shortened relatively (figure 2 bottom).

Figure 3 shows the detailed representation of the sensor element 11 (left) as well as a typical course of the temperature in one direction (designated in figure 3 as x-direction) perpendicular to the plane of the sensor element 11 (right) and renders visible the principal difficulty of the temperature automatic control. The heating structure 32 is disposed between the gas sensitive layer 33 and a sensor substrate 31. Even if the temperature of the

heating structure 32 would be constant completely, then nevertheless therewith no constant temperature under all circumstances of the gas sensitive layer 33 can be accomplished, since the temperature gradient between the gas sensitive layer 33 and the surrounding air is very large and is influenced by the heat delivered by the sensor element 11 based on radiation and convectively.

If for example the temperature of the heating structure 32 is automatically controlled to 350 degrees centigrade, then the temperature in the ambient air can vary in practical situations between minus 40 degrees centigrade and plus 80 degrees centigrade. A temperature deviating from the heater can be determined at the surface of the gas sensitive layer 33 based on the temperature gradient between the surroundings and the sensor element 11, wherein the deviating temperature is typically smaller as compared with the set point value.

The thermal energy delivered by the sensor element 11 to the surroundings is on the one hand a function of the temperature gradient and on the other

hand a function of the flow speed of the air relative to the sensor element 11.

Even in case of only the smallest air motions in the neighborhood of the sensor element 11, the temperature gradient changes between

-the heating structure 32 maintained at a constant temperature,

-the gas sensitive layer 33 and the

-temperature of the surrounding air.

Therefore one will be determining practically always substantial variations of the sensor resistance in standard air despite expensive electronic automatic controls, which situation in the past has substantially limited the deployment of semiconductor sensors, since the base resistance of the gas sensitive layer 33 massively varies with the temperature.

Figure 4 shows a sensor device according to the present invention. A sensor element 11 is disposed in a casing 40, which casing 40 is air technically closed and does not allow access to the heated sensor element 11 for air motions outside of the casing 40. The casing 40 is preferably constructed

such that the inner space of the casing 40 is insulated thermally relative to the surroundings.

After some time of thermal balance between the heating structure 32, the sensor substrate 31 as a thermal storage and the gas sensitive layer 33 is formed in the casing 40, because also the air disposed in the surroundings of the gas sensitive layer 33 is heated to a higher level and the temperature gradient between air and sensor element 11 is thereby decreased. The undesirable variations of the sensor resistance caused by the temperature gradient between air and the sensor element 11 are in this fashion substantially reduced according to the present invention.

The casing 40 shows according to the present invention a semi-permeable diffusion layer 47, which diffusion layer 47 is practically in permeable for air flows, however can be penetrated by diffusing air particles and gas particles. The diffusion layer 47 comprises for example finest capillary plastic (Teflon, stretched foils and the like) or for example a sinter body out of metal, plastic, glass or ceramics. The diffusion layer forms the cover face

of the casing 40 according to a preferred embodiment of the invention. Gases diffuse through the diffusion layer 47 into the casing 40 or out of the casing 40 based on the different particle pressures inside and outside of the casing 40 according to the present invention wherein however an air circulation through the diffusion layer 47 is practically suppressed.

Thermal currents induced based on air motions through the semi-permeable diffusion layer 47 are excluded or at least very strongly limited.

The connection wires 40 for the sensor element 11 are preferably sealing against gas and are led through the casing floor 45. Preferably this is performed by melting the connection wires 44 into a glass layer 49 covering the casing floor 45.

According to a preferred embodiment of a sensor device according to the present invention the casing jacket 48, the casing floor 45 as well as the diffusion layer 47 and thereby the casing 40 are constructed heat insulating and/or thermally insulating.

It is accomplished hereby in combination with a very precise heating automatic control that no effects of the ambient temperature onto the sensor resistance in standard air show up any longer over very wide temperature range.

It is a further advantage that the energy requirement of the sensor element 11 can be substantially decreased by the heat insulating and/or thermally insulating construction of the casing 40 and of the diffusion layer 47, which is very important and advantageous during operation with batteries.

It is known to evaluate the difference between an actual signal and the average value as was already recited above in connection with the illustration of the state-of-the-art. If suddenly events occur to which the sensor responds then these sudden events can be very good detected with this method. Slow and/or small changes of the sensor resistance in contrast lead to no evaluations or, respectively, switching signals.

Figure 5 illustrates this known method. The actual sensor signal 51 is averaged over a certain time period and added to a constant value such that an averaged signal results disposed on average slightly above the sensor signal, which is referred to as reference signal 52. If events 53,54 occur, which change the value of the actual sensor signal to values above the reference signal 52, then a switching signal is triggered.

Slows changes of the actual sensor signal are ignored. In contrast a switching signal is reliably generated upon occurrence of sudden concentration increases of oxidizable gases in the surrounding air.

In many cases it is however very important that also a slow rise of gas concentrations is reliably detected, for example in cases where the concentration of toxic gases slowly increases, which has to be detected at any rate. The method illustrated with reference to figure 5 can therefore not be applied without modification.

The heating power is influenced by an additional value (relative to the

temperature) according to the present invention method for operating of a sensor device according to the present invention. An interference value switch on is performed from an automatic control technology point of view.

The observation that changes of the electrical parameters of the gas sensitive layer 33 of the sensor element 11 (resistance, capacitance, inductivity) can be derived both from the offering of oxidizable or reduceable gases as well as can be the result of variations of the air humidity or of the temperature is a basis of the invention idea.

Only the detection of oxidizable gases is described in the following for purposes of simplicity. Reduceable gases behave in principle inversely, that is they increase also for example the sensor resistance, whereas in contrast oxidizable gases reduce the sensor resistance. The invention is sensibly applicable, even though inversely, also for reduceable gases.

Figure 6 serves for illustrating the operational connections. The sensor in standard air delivers an actual sensor signal upon a heating power of 6b,

characterized by 6a in figure 6, at the start. In the following the sensor is subjected to a gas impulse, wherein the time duration of the gas impulse is featured in figure 6 at the bottom.

The curve section 68 in figure 6 shows the course of the actual sensor signal in case of an uninfluenced heating power. In case of a non-influenced heating power the actual sensor signal returns to the starting value only after a longer time period after the end of the gas impulse. The section of the curve 68 following to the end of the gas impulse shows this reaction of the actual sensor signal to the gas impulse during constant heating power, wherein the constant heating power is illustrated in figure 6 by line 62.

The heating power with interference value switch on illustrated in figure 6 by the curve 63 in contrast leads to an actual sensor signal influenced by the heating power, wherein the actual sensor signal follows the curve section 64 shown in figure 6.

If the heating power is then always tracked (curve 63) for example

proportional in the sense of a temperature increase, when the actual sensor signal passes through a change, then the actual sensor signal returns significantly quicker to the starting value. The section of the curve 64 following to the end of the gas impulse shows this reaction of the actual sensor signal onto the gas pulse in case of a tracked heating power, which is illustrated in a curve 63.

It is essential that in case of a gas concentration actually present at the sensor, the reactions of the gas sensitive layer 33 occur at any rate with the gas. The temperature sensitivity of the sensor signal is decreased by the interaction with the gas. The change of the sensor signal caused by the temperature tracking is therefore smaller during the gas impulse as compared with prior to or after the gas impulse. In other words: the sensor signal reacts during the gas impulse only relatively weak to a change in the heating power and are thus interference value switch on. The gas induced reduction of the actual sensor signal assumes therefore approximately the same course upon tracking of the heating power as it is present in case of an otherwise identical test arrangement without temperature tracking. This

means that the in each case falling branches of the curve 64 and 68 in figure 6 after the start of the gas impulse have an approximately equal course.

If however the reaction of the actual sensor signal is for example caused by a change of the air humidity or by a change of the air temperature, then the temperature sensitivity of the sensor signal does not change or changes only a little. A change of the air humidity or a change of the air temperature therefore exert substantial and continuing influence onto the actual sensor signal in case of a non-influenced heating power (curve section 65 in figure 6).

If however already at the start of such an interaction the heating power was tracking, then the influence of the sensor signal effected by the temperature tracking is substantially larger as in the case of a gas impulse. In other words: the sensor signal reacts heavily to a change in the heating power and thereby to the interference value switch on. Therefore the change of the sensor value caused by a change of the air humidity or by a change of the air temperature is not only much smaller, but also timewise clearly shorter

(curve section 66 in figure 6) as is the case of a non-influenced heating power (curve section 65 in figure 6), and already the falling branches of the curves 65 and 66 in figure 6 have a not coinciding course.

Thus by way of the time behavior of the sensor signal it is possible to distinguish between a gas pulse and humidity pulse based on the invention method. The reaction of the sensor signal to humidity pulse is according to the present invention compensated to a such substantial part by the heating tracking.

Therefore the automatic heating control of the sensor is constructed such according to the present invention that the temperature is the guide value of the heating automatic control or and that a perturbing value is switched onto the automatic control, wherein the perturbing value is derived from attenuation of the actual sensor signal from a standard value in case of standard air.

As was illustrated with reference to figures 1 and 2, both the signal

processing as well as the automatic heating control can advantageously be controlled by a single single-circuit controller (uC).

The advantageously result of a combination of

a. An arrangement of the sensor element 11 in a thermally insulated ore, respectively heat insulated casing 40 with a thermally insulating or, respectively, heat insulating diffusion layer 47, wherein a gas access to the sensor element 11 can be performed through the diffusion layer 47 by diffusion and without air motion,

b. A diffusion caused gas access to the sensor without air motion,

c. The heating of the sensor element 11 by automatic control of the temperature, wherein the relative deviation of the actual sensor resistance relative to the resistance of the sensor element 11 under standard conditions is switched on to the automatic control circuit as a perturbing value,

comprises that the sensor signal quickly and nearly exclusively follows and tracks the actual contents of oxidizable air content materials and exhibits substantially less drift appearances as are known at the present.

If an evaluation is performed which compares the actual sensor value with an average value obtained over the time period, then substantially smaller variations of the sensor signal under standard conditions can be assumed, in particular then, when the system built up a stable situation after some time.

According to a variation of an embodiment of the invention method therefore the time period through which the average value of the actual sensor signal is formed in order to serve as a comparison value to the actual sensor value, is not constant, but the time period increases again and again in the course of the operational time of the system.

The first comparison value is obtained out of the average value over a relatively short time period, since the system immediately upon switching on is subject necessarily to high self dynamic variations. This time period is

increased after the switch on phase and the time period reaches finally in the built up state a substantially longer integration time. Since the average value in principle can coincide precisely with the actual sensor signal, a certain amount is deducted from the calculated average value in order to form the so-called reference value.

The amount to be deducted is very large in the initial phase according to a preferred embodiment such that the reference value shows a large distance to the sensor value. This is important in order to prevent that in the not built-up state signals are triggered even though no significant gas concentration change occurs. The amount is successively decreased in the further time course, such that the reference value approaches more and more to the sensor value in the built-up state.

Further refinements can be introduced. According to a further variation of an embodiment of the invention method the reference value is brought again to a larger distance relative to the sensor value after violent gas induced sensor reactions, because based on experience violent reactions of the sensor

lead to temporarily instable sensor situations.

According to a further variation of an embodiment the calculation of the average value is performed again over shorter time periods, if a gas induced heavy signal change has occurred. According to a further embodiment the calculation of the average value is dispensed with for that time period during which a gas induced sensor signal change occurs.

Despite the recited steps the actual gas level can rise at such a slow speed that the average value essentially follows this rise. In this case slowly substantial gas concentration could form without that the precedingly described trigger condition would be fulfilled, according to which the actual sensor signal assumes a smaller value as compared to the reference value obtained by calculation.

According to a further variation of an embodiment in addition a minimum value is fixed for the reference value, wherein the actual reference value can never become smaller as compared with this fixed minimum value. The

minimum value is selected such that this limit is not reached by sensor caused variations, but on the other hand the gas concentration, which gas concentration can be coordinated to this sensor signal, does not yet have a permanently damaging effect on the human being, or, respectively in case of a for example monitoring of explosion limits (for example methane air mixtures) this limit is disposed in the large safety distance relative to the explosion limits.

If the jump like changes of the humidity or of the temperature occur (for example in case of the application of the sensor at the suitable location in or at the breathing protective masks for purposes of filter or sealing monitoring), then the effect of these influence onto the sensor resistance will be absolutely small and only temporary upon employment of an invention method.

Nevertheless an erroneous signal triggering can occur, which then would be an undesired erroneous alarm.

According to a further variation of an embodiment therefore the time wise staggered evaluation is performed, which is illustrated with reference to figure 7.

A reference value 77 is disposed under the sensor standard level 71. If a gas pulse decreases the actual sensor signal by a certain amount (curve section designated with reference numeral 72), then the reference value is undershot and thereby the switching criterion is fulfilled. This triggers a kind of `quiet prealarm`, however the switching signal is not triggered according to the present invention. Only when the switching criterion remains fulfilled for certain time period illustrated in figure 7 by the time duration 73 then a switching signal is triggered, wherein the switching signal is maintained during the residual time period (designated with the time duration 74 in figure 7), during which time period the actual sensor signal remains lower as compared to the reference value.

If in contrast to very short time and therefore practically to be neglected gas impulse occurs or in case a humidity impulse to be compensated according

to the invention occurs, which impulse triggers a reaction of the actual sensor signal as illustrated with reference numeral 75 in figure 7 then no switching signal is triggered according to the present invention.

According to a further variation of the invention method the time duration 73 of figure 7 of the prealarm is not fixedly defined but represents a function of the quickness of the sensor signal change or function of the absolute change amount relative to time.

If thus within a predetermined time period there occurs a very large sensor signal change, then the time period of the prealarm can be shortened. This is advantageous in order to be able to hold the time period up to the triggering of the alarm as short as possible in case of in fact suddenly occurring large gas concentrations.

Similar result can be accomplished when the sensor signal is average over two different time periods, for example both over time period of 20 seconds as well as over time period of 300 seconds. A certain amount of for example

2 percent of the standard value or the like is deducted from the average value formed over the longer time period as previously recited. The thus determined values are compared with each other.

If the average value formed over the shorter time period is smaller as the value resulting by averaging over the longer time duration and deduction of a certain amount (for example 2 percent), then a switching signal is triggered.

Mathematically this can be expressed by the formation of the following difference for example for the case, that the longer time duration is 10 times as long as the shorter time duration.

$$\frac{S_1 + S_2 + S_3 + \ldots + S_n}{n} - 0{,}98 * \frac{S_1 + S_2 + S_3 + \ldots + S_{(10*n)}}{10*n} = Y$$

The switching criterion is reached when the value Y becomes negative.

However it is not sensible frequently to deduct only a constant value from the average value for forming a reference value, since the sensor characteristic curve (sensor signal depending on the gas concentration) is usually a nonlinear curve.

This means that for example 10 ppm (parts per million) of a certain gas depending on the basis resistance of the gas sensitive layer effects different resistance changes for the case that the ohmic resistance of the gas sensitive layer 33 is employed for forming the actual sensor signal. The relative resistance change caused by 10 ppm of a gas is substantially smaller for example by low basis resistance as compared to a high base resistance. This fact can be taken into consideration by taking into consideration the sensor characteristic curves of different object gases in the calculation of the reference value based on the obtained average value.

The use of the described sensor system is particularly critical, in case the system is taken in cooperation, while already a substantial gas load is

present. Since the system namely cannot measure absolute concentrations, but only changes (referring to the reference value) within the observation time period, the system would not deliver any suggestion (switching signal, alarm) relative to the actual present load of gas.

This problem situation is resolved according to the present invention by short term increasing of the temperature of the gas sensitive layer. The temperature increase effects on the one hand the shifting of the reaction balance within the gas sensitive layer, which shows in a change of the sensor signal, and on the other hand the sensor is short term operated on the different (temperature dependent) characterizing curve. The capturing and the evaluation of the sensor signals prior to, during and after the short-term temperature increase enables conclusions relative to a possibly present gas load.